A New Protection Strategy for Micro-grid Based On Relative Measured-Impedance and Regional Negative Sequence Component

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ABSTRACT

Aiming at the problems existing in micro-grid, a set of protection schemes , which are according to the fault characteristics of micro-grid system with different voltage levels of 10kV and 400V in distribution network, are proposed in this paper. According to the simulation results, it is verified that the protection scheme can detect various fault types of micro-grid in different voltage levels. The protection scheme has good rapidity, reliability and selectivity.

INTRODUCTION

Micro-grid is an independent and controllable system constituted of series of distributed resources and load. It is generally located at the end of a medium voltage distribution network or a low voltage distribution network[1-2]. The micro-grid has two operation modes: connection and isolation. The reliability and continuity of the system power supply can be ensured through seamless switching between different operation modes. The distribution network with the medium and low voltage micro-grid has the following features[3-6]:

(1)In the micro-grid with 400V, the line is short. When short circuit fault occurs, the voltage at the protection installation drops greatly, conventional distance protection is not applicable. While in the micro-grid with 10kV, the bidirectional power flow makes the 10kV micro-grid current characteristics different from the unidirectional current characteristics of the conventional distribution network.

(2)In the connection state, the fault current is large; while in the insulation state, the fault current is relatively small.

(3)The protection scheme of distribution network with medium and low voltage micro-grid is different from the traditional distribution network.

Now many experts and scholars have made a lot of research on the micro-grid. An improved inverse time over-current protection was given in the reference [7]. It adds a low voltage acceleration action factor to failure criteria to achieve low-voltage inverse time over current micro-grid protection without communication. The literature [8] uses tree diagram to describe the micro-grid, regarding the circuit breaker as the edge of the graph. With the network digital protection as a means, a micro-grid can be viewed as edge of the graph. With the networked digital protection algorithm based on a graph, an model is proposed. In order to achieve fault phase selection for the external faults of micro-grid, positive phase sequence components, negative sequence

components and zero sequence components relations are introduced in document [9-10]. A single phase grounding fault components and *dq* transformation is proposed. These protection strategies have made certain improvements to the traditional methods of micro-grid, but they have not considered the characteristics of faults at various voltage levels systematically and cannot overcome the systemic problems of the micro-grid. The reliability of its protection needs further study.

In view of the above problems, this paper proposes a set of protection schemes for distribution networks with medium and low voltage micro-grids. Through simulation analysis, it is verified that the protection scheme can detect various fault types of the micro-grid in different voltage levels, and it has rapidity, reliability and selectivity.

PRINCIPLE

The distance protection and the positive sequence component protection methods applied to 10kV and 400V micro-grids are presented in this paper, which can meet the protection requirements of medium and low voltage micro-grids, as shown in Figure 1. The protection scheme is as follows:

(1)A protection scheme of 10kV micro-grid which is based on the relative measurement impedance and inverse time limit principle.

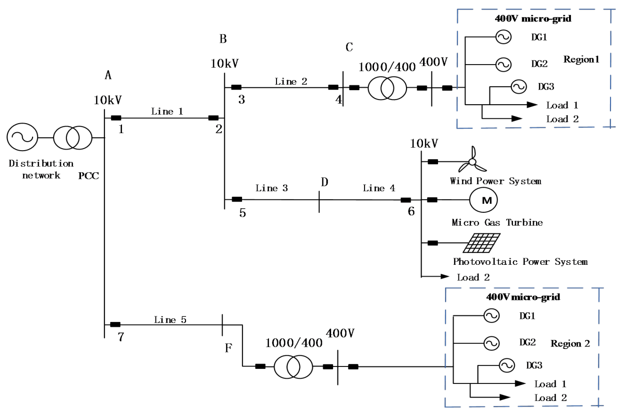

Figure 1 Wiring diagram of distribution network system with medium and low voltage micro-grid

(2)For the 400V micro-grid, a positive sequence component based directional component is used as the main protection and a harmonic distortion rate (THD) is used as a back up protection strategy.

A NEW PROTECTION STRATEGY FOR MICRO-GRID

The principle of relative impedance protection for 10kV line

The relative impedance coefficient can be obtained from Figure 2, its formula is as shown in Formula (1) :

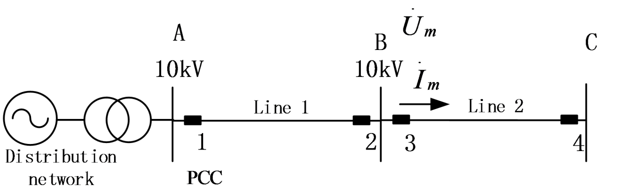

Figure 2 Connection diagram of medium voltage feeder system

$$Z_B = \frac{1}{Z_L}\frac{\dot{U}_m}{\dot{I}_m} \qquad (1)$$

where Z_B and Z_L indicate the relative impedance of the protected line and the impedance of the protected line. Also, $\dot{U}_m$ 、 $\dot{I}_m$ stand for the measuring voltage and current at the protection installation.

The q axis voltage formula obtained by a, b, c three phase voltage via Parker transform, as shown in Formula (2) :

$$V_q = \frac{2}{3}\begin{bmatrix} \sin \omega t, \\ \sin(\omega t + 120^0) \\ \sin(\omega t - 120^0) \end{bmatrix}^T * \begin{bmatrix} \dot{V}_a \\ \dot{V}_b \\ \dot{V}_c \end{bmatrix} \qquad (2)$$

Therefore, considering the relative impedance calculation formula of modified q axis, action voltage as shown in Formula (3):

$$V_q^* = \frac{1}{T}\int_0^T \frac{Z_B V_q}{V_{qN}} dt \qquad (3)$$

where V_q^* and T indicate, respectively, the action voltage of q axis and the period of the fundamental frequency signal of the power grid. Further, V_q and V_{qN} indicate the q axis voltage and the rated voltage of q axis. An improved inverse time formula based on modified q axis voltage as shown in Formula (4):

$$t = \begin{cases} K[\frac{1}{(\mathrm{V}_{op} - \mathrm{V}_q^*)^{0.02}} - 1] & \mathrm{V}_q^* \le \mathrm{V}_{op} - 0.02 \\ 2 & \mathrm{V}_q^* > \mathrm{V}_{op} - 0.02 \end{cases} \qquad (4)$$

Firstly, the relative value of the q axis operating voltage is calculated, and the q axis operating voltage is corrected by using the relative measured impedance value. After the inverse time delay is applied, fault line is tripped.

The protection strategy of 400V

Fault direction discrimination of low voltage micro-grid based on positive sequence directional element

In the system where the micro-grid is connected to the grid, if a fault occurs, the location of the fault may be located on the distribution network side, the tie line or within the 400V micro-grid, as shown in Figure 3.

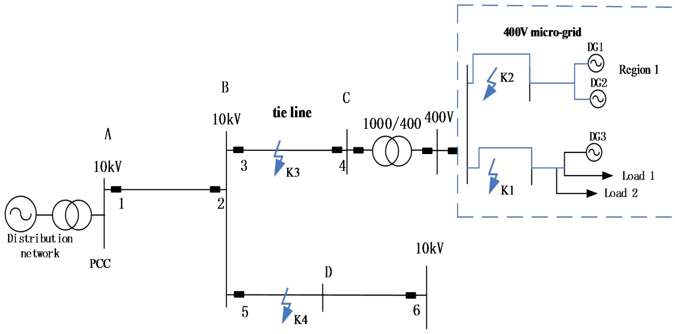

Figure 3 Internal and external faults in 400V micro-grid

The positive sequence component measurement impedance is defined, as shown in Formula (5) and (6).

$$Z_{B1} = \frac{\Delta \dot{U}_{B1}}{\Delta \dot{I}_{B1}} \qquad (5)$$

$$Z_{B1} = \frac{\Delta \dot{U}_{B1}}{\Delta \dot{I}_{B1}} + \frac{\Delta \dot{U}_{C1}}{\Delta \dot{I}_{C1}} \qquad (6)$$

Let $\varphi_B = \arg(Z_{B1}), \varphi_{BC} = \arg(Z_{BC1})$. According to the above analysis, the angular ranges of φ_B and φ_{BC} at K1~K4 points where a fault occurs are shown in Table 1.

Table 1 The range of positive sequence impedance angle in the case of internal or external failure of 400V micro-grid

Fault Location	K4	K3	K1、K2
φ_B	0°—90°	180°—270°	180°—270°
φ_{BC}	0°—90°	180°—270°	0°—90°

It can be known from the analysis that when the short circuit occurs on the distribution network side, the range of the calculated positive sequence impedance Z_{B1} is (0°,90°). When the fault occurs between the tie line and the micro-grid, the range of the impedance Z_{B1} is (180°,270°). So the short circuit faults on the distribution network side can be determined by calculating the angle of impedance Z_{B1}. Similarly, the range of impedance angle of Z_{BC1} is (180°,270°) when the fault occurs on the tie line, and the range is (0°,90°) when the fault occurs outside the tie line. Therefore, the short circuit of the tie line can be determined by calculating the angle of the impedance Z_{BC1}.

In conclusion, the criterion for judging the internal fault of the 400V micro-grid is shown in Formula (7):

$$\begin{cases} 0^\circ < \varphi_{B1} < 90^\circ \\ 0^\circ < \varphi_{BC1} < 90^\circ \end{cases} \quad (7)$$

Internal short circuit fault protection

When the alternative current, which is generated by inverter, flows over the micro-grid and the distribution generation system, it has a certain number of harmonics. The number of these harmonics is related to the frequency of modulation wave. It is reasonable to locate the fault by using the magnitude of the THD sum. That is, if sum (THD1) > sum (THD2) then the fault occurred at the point of K1.

SIMULATION ANALYSIS

The protection strategy simulation of 10kV line

The system wiring diagram of the medium and low voltage micro-grid shown in Figure 1 is simulated. The parameters of the system are shown in Table 2, and the voltage values of each node in normal operation are shown in Table 3. The V_q reference value in the calculation of the voltage is the magnitude of the phase voltage of each node in normal operation in medium voltage micro-grid. The line type is transmission cable, and the reference voltage of the system is 0.38kV in low voltage micro-grid.

A three-phase short circuit fault occurs at the midpoint of line B-C during grid-connected operation. The simulation time is 2s, and the fault occurs at 1s.

The short circuit data records under various types of simulation verification are shown in Table 4.

Table 2 The internal line parameters of micro-grid

Line	A-B	B-C	C-E	A-F
Impedance/ohm	0.632	0.316	0.316	0.632

Table 3 Voltage values of each node in normal operation of micro-grid

Node	A	B	C	E	F
Connection Line voltage	0.394	0.385	0.378	0.381	0.386
Island line voltage	0.369	0.376	0.373	0.383	

Table 4 Short circuit data records in various types of cases

Fault Type	Three-phase short circuit		A-B two-phase short circuit		Islanding operation	
	P1	P3	P1	P3	P1	P3
Weighted edge length	1.7	0.5	1.63	0.45		0.5
V_q*	0.84	0.58	0.95	0.83		0.25
Edge voltage value	1.43	0.29	1.55	0.37		0.13
Action time limit	2	0.13	2	0.16		0.06

Simulation of 400V protection strategy

The fault setting of 400V low voltage micro-grid is shown in Figure 3. The simulation results are shown in Table 5. It can be seen from Table 5 that when various failures occur at the point of K1 and K2, the positive sequence impedance angles satisfy the criterion requirements and are judged as internal faults. When the fault occurs outside the zone (K3, K4) or normal operation, the angle of the positive sequence impedance does not meet the criterion requirements, and it is judged as an out-regional fault.

Through the simulation of the harmonic distortion rate,as shown in Table 6. It can be seen that the criterion of harmonic distortion rate proposed in this paper can be used to distinguish the phase of the fault phase in the low voltage micro-grid. The third harmonic distortion rate of the fault phase is greater than the fourth harmonic distortion rate. By comparing the third harmonic distortion rate and the fourth harmonic distortion rate, the fault phase can be identified.

Table 5 The result of the criterion of the positive sequence direction element of the micro-grid

Fault Type	Fault Location	φ_B /°	φ_{BC} /°	Result	Fault Type	Fault Location	φ_B /°	φ_{BC} /°	Result	Fault Location	φ_B /°	φ_{BC} /°	Result
BC	K1	23	30	inside	BCG	K1	47	26	inside	K1	23	30	inside
	K2	226	239	outside		K2	249	228	inside	K2	235	217	outside
	K4	231	32	X		K3	246	32	X	K3	241	28	X
Normal		248	59	X									

Table 6 Harmonic distortion rate judgment result

Fault Type	Fault Location	THD3a/THD4a	THD3b/THD4b	THD3c/THD4c

Normal		0.011/0.026	0.012/0.026	0.011/0.025
AG	F3	0.253/0.169	0.030/0.037	0.031/0.038
	F4	0.076/0.209	0.013/0.029	0.016/0.034
BC	F3	0.012/0.026	0.298/0.169	0.299/0.185
	F4	0.0159/0.029	0.079/0.262	0.087/0.237
BCG	F3	0.019/0.025	0.339/0.218	0.360/0.221
	F4	0.011/0.025	0.109/0.311	0.109/0.325
ABC	F3	0.475/0.264	0.632/0.329	0.605/0.304
	F4	0.107/0.441	0.141/0.583	0.125/0.520

CONCLUSION

With the continuous development of micro-grid, the reliability of its protection system is very important. The protection system should be designed according to the characteristics of the micro-grid. A new micro-grid protection scheme based on relative measurement impedance and sequence component theory can be adopted to the particularity of fault characteristics of micro-grid. In addition, a method which is based on the harmonic distortion rate is proposed in this paper, it can realize the detection of the fault type and has practical value.

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